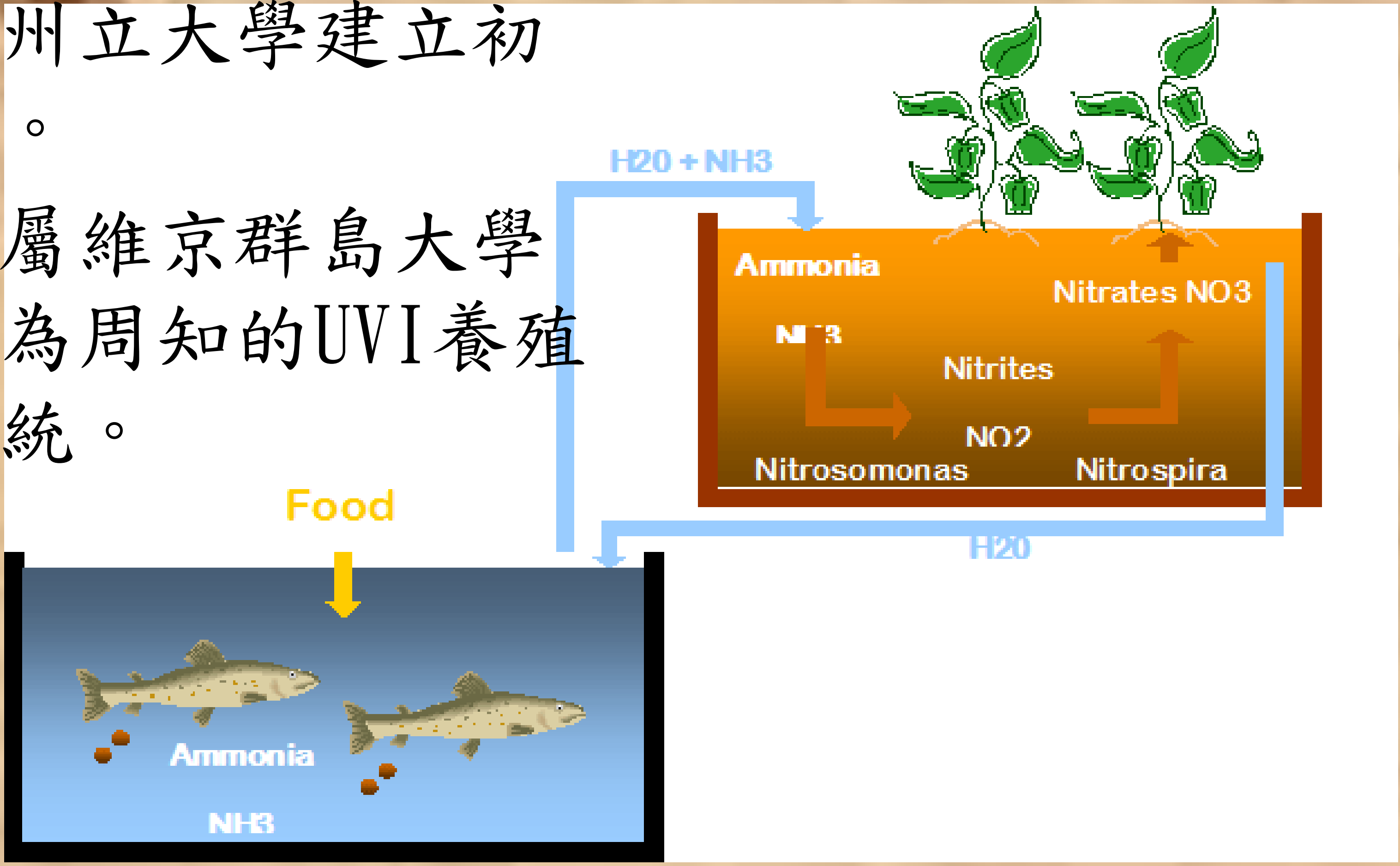
各國養殖水耕(Aquaponics)技術研究與產業概況

作物環境課 賴昭宏

Aquaponics = Aquaculture + Hydroponics

- 在1970~80年間，由北卡羅來納州立大學建立初始模型。
- 1980美屬維京群島大學建立廣為周知的UVI養殖水耕系統。



養殖水耕的優點

- 節省水資源。

  5,000~20,000L/Kg牛肉

  2,500~375,000L/Kg魚肉(半密集或密集非循環水養殖)

  100~L/Kg魚肉(密集循環水養殖)

- 減少個別系統操作成本，減少養殖與水耕廢水汙染。

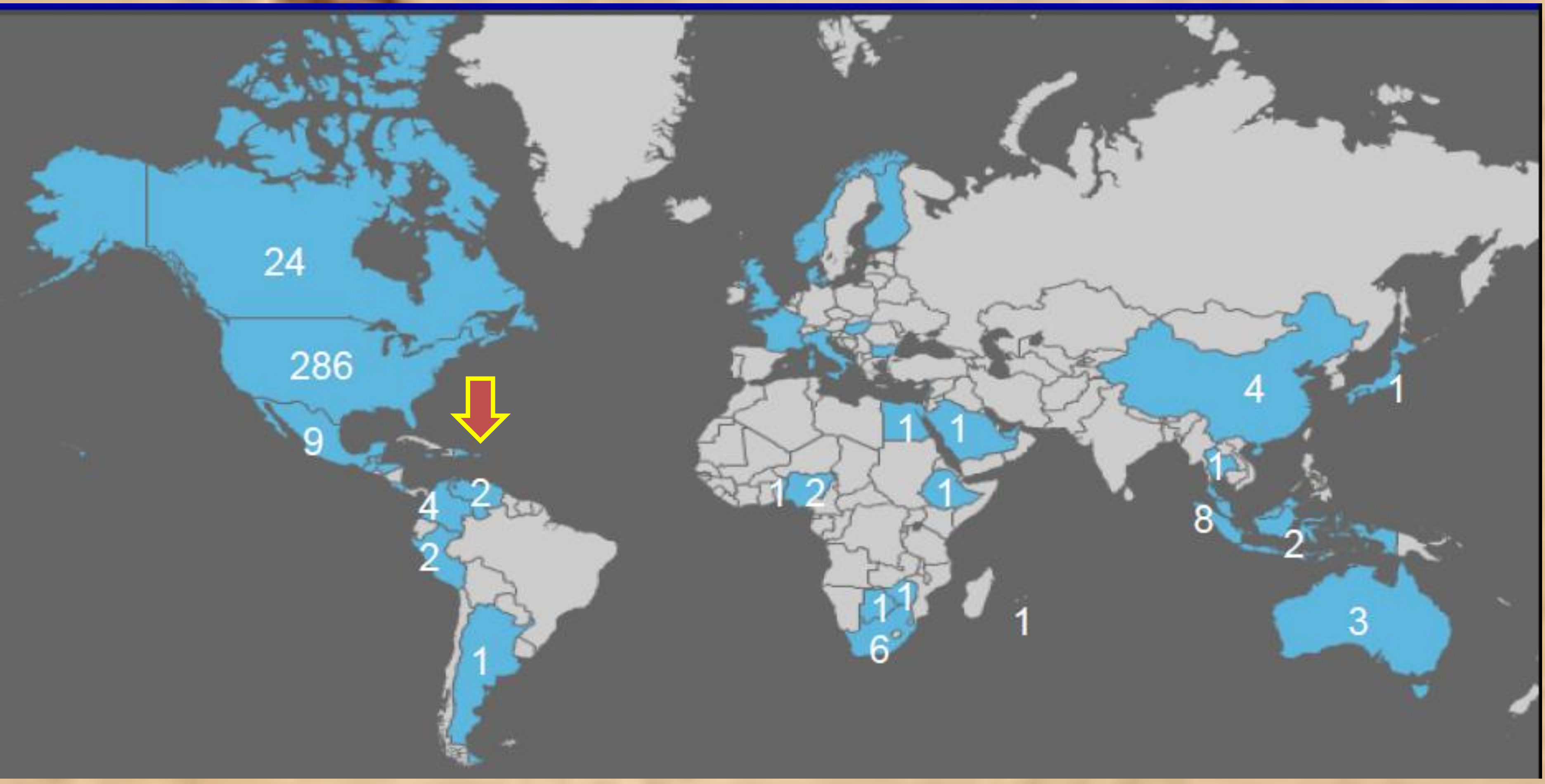

A Media Beds
B Floating Rafts
E Wicking Beds
C Nutrient Film Technique
D Vertical Towers
F Dutch Buckets

Table 1. Advantages, disadvantages and nutrient uptake for different grow components in aquaponics with regard to different practical and productivity aspects.

	Media-Based Growing Bed	*DWC*	*NFT*	*Soil*
Advantages	- Biofiltration: media serves as substrate for nitrifying bacteria [32]; - Act as a solids filtering medium; - Mineralization in grow bed; - Colonized by a broad microflora	- Constant water flow; - Small sump tank needed; - Ease of maintenance and cleaning [33]	- Constant water flow - Small sump tank needed; - Ease of maintenance and cleaning; - Require smaller volume of water; - Light hydroponic infrastructure, suits well for roof farming	- Less infrastructure - Natural roots environment; - Colonized by broad microflora and fungi [34]; - Accepted as "organic way of production"
Disadvantages	- If flood and drain method: sizing and reliability plus large sump tank needed; - Heavy hydroponic infrastructure; - Maintenance and cleaning difficult; - Clogging leading to water channeling, inefficient biofiltration and inefficient nutrient delivery to plants [33]	- Separate biofilter needs to be added [32]; - Require large volume of water; - Heavy hydroponic infrastructure; - Device for roots aeration mandatory [35]	- Separate biofilter needed; - Lower yields (showed for lettuce by) [32]; - Expensive material; - the system is less stable as there is less water,	- Small control on the soil nutrient solution; - Good soil not available everywhere; - More vulnerable for diseases; - Lower basil and okra yield than in aquaponics [29]
Nutrient uptake	- High	- High	- Lower because smaller root-water contact area	- Lower

UVI系統簡介

- 由美屬維京群島大學(University of Virgin islands)James E. Rakocy於1980年代建立。
- 系統包含養殖槽、過濾槽、曝氣槽、生物過濾槽及水耕植床組合而成，並建立不同配比之養殖密度、飼料投餵量與蔬菜種植量，常用魚種包括吳郭魚，鯰魚等，蔬菜種類則以蘿勒、香草植物、萵苣、葉用甜菜、番茄、胡瓜及黃秋葵等。
- 羅勒產量為土耕產量3倍，黃秋葵產量為土耕產量18倍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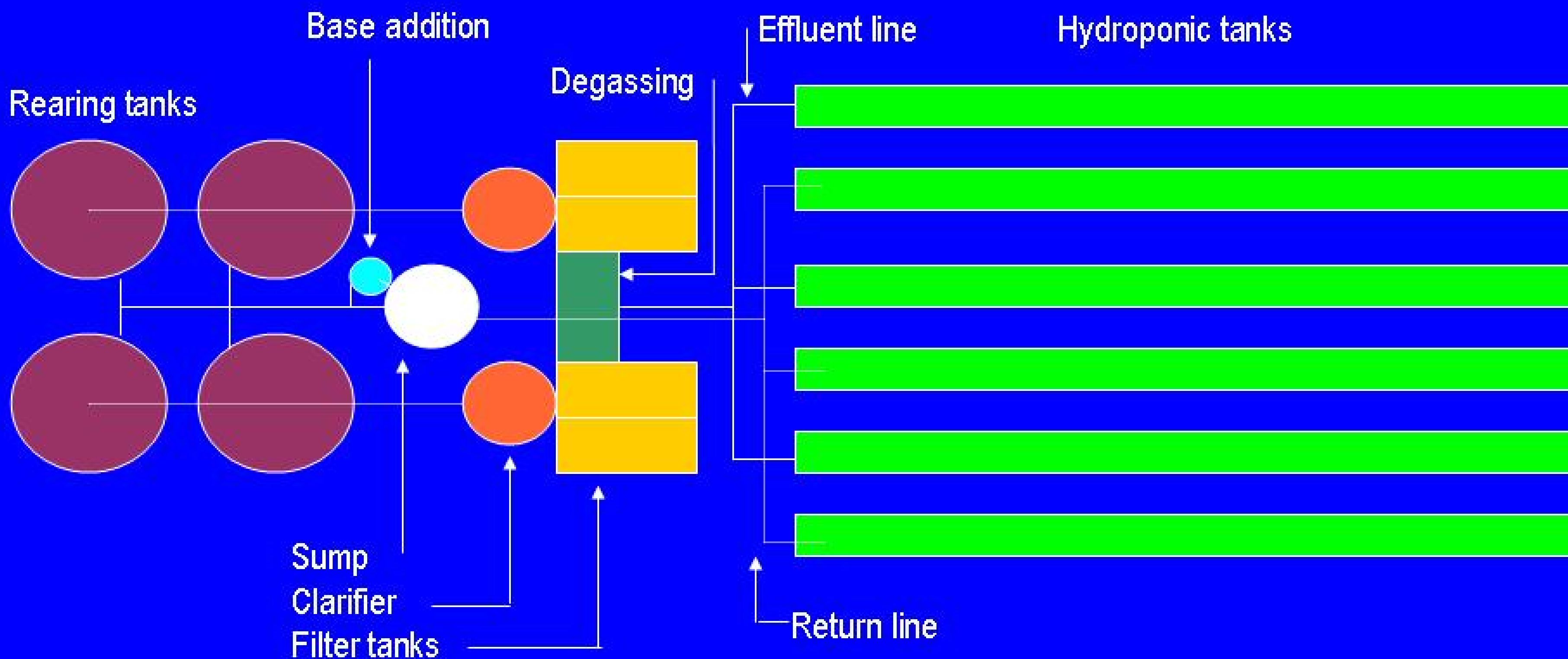
UVI Aquaponic System



養殖空間:4*7.8M^3
投餌量與種植面積比:60~100g/M^2/day

栽培面積:6*30.5M*1.2M=214M^2

Graphic: UVI Aquaculture Pro


Photo:

1.principles of aquaponics - by Dr. James Rakocy

Use a feeding rate ratio for design calculations
Keep feed input relatively constant
Supplement with calcium, potassium and iron
Ensure good aeration
Remove solids
Be careful with aggregates
Oversize pipes
Use biological control
Ensure adequate biofiltration
Control pH

Table 2. Preliminary production and economic data from the UVI aquaponic system at the Crop Diversification Center South, Alberta, Canada.[1] (Data courtesy of Dr. Nick Savidov)

Crop	Annual production		Wholesale price		Total value	
	lb/ft^2	$tons/2690\ ft^2$	Unit	$	$\$/ft^2$	$\$/2690\ ft^2$
Tomatoes	6.0	8.1	15 lb	17.28	6.90	18,542
Cucumbers	12.4	16.7	2.2 lb	1.58	8.90	23,946
Eggplant	2.3	3.1	11 lb	25.78	5.33	14,362
Genovese basil	6.2	8.2	3 oz	5.59	186.64	502,044
Lemon basil	2.7	3.6	3 oz	6.31	90.79	244,222
Osmin basil	1.4	1.9	3 oz	7.03	53.23	143,208
Cilantro	3.8	5.1	3 oz	7.74	158.35	425,959
Parsley	4.7	6.3	3 oz	8.46	213.81	575,162
Portulaca	3.5	4.7	3 oz	9.17	174.20	468,618

[1]Ecomonic data based on Calgary wholesale market prices for the week ending July 4, 2003.

Table 6. Comparison of basil yield, mean plant weight, survival and gross income with three production methods.

Production Method	Annual Yield (kg/m^2)	Annual Yield ($kg/214\ m^2/yr$)	Mean Plant Weight (g)	Survival (%)	Income (US$/ m^2/yr)	Income (US$/214 m^2/yr)
Batch	25.0	5,341	286.5	84.7	550	117,700
Staggered	23.4	5,008	244.7	-	515	110,210
Field	7.8	1,669	104.4	100	172	36,808

Murray Cod model-RMIT University澳洲

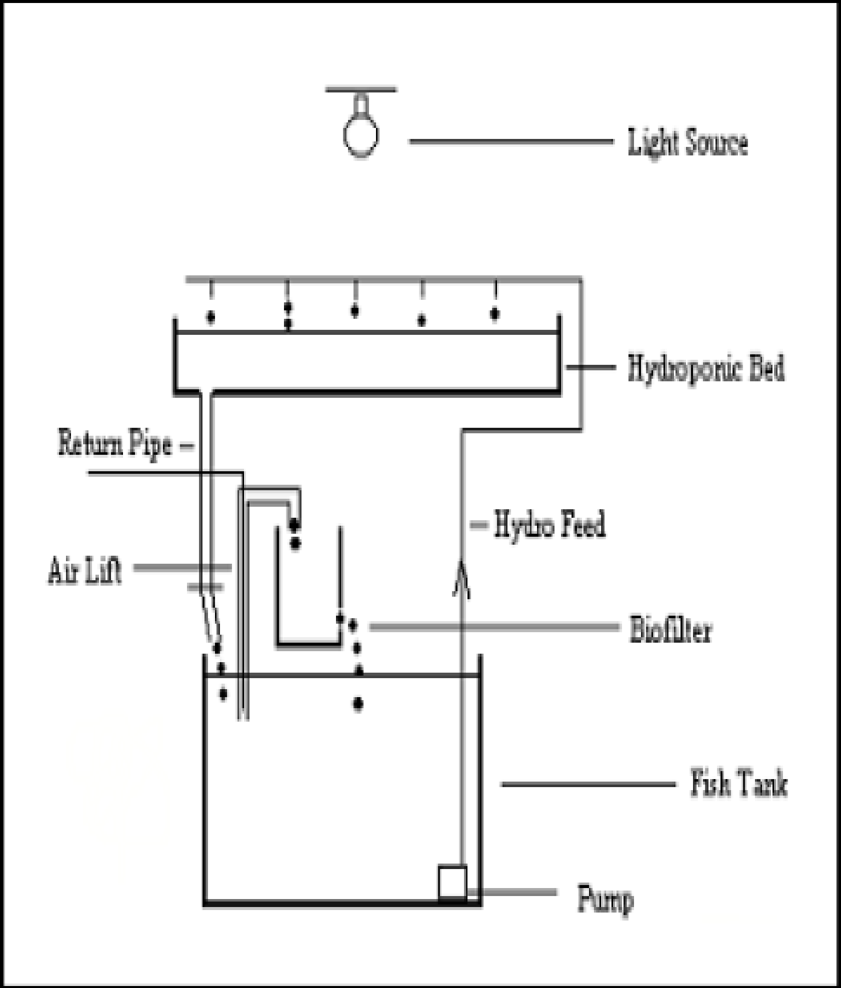


Figure 1: Schematic representation of a single Aquaponic test unit.

Figure 2 (above): Aquaponic test system, showing aquaponic units consisting of fish tanks (below) and hydroponic gravel beds containing young lettuce seedlings (above).

igure 3 (below): Fish rearing component of a single

Table 2
Murray Cod wet weight gain, specific growth rate (SGR), food conversion ratio (FCR) and food Consumption; lettuce mean biomass gain and mean yield (g plant^{-1} & kg m^{-2}); mean net phosphate and nitrate concentrations, mean weights and removal rates for Control, Gravel, Floating and NFT treatments.

Parameter	Control	Gravel	Floating	NFT
Fish				
Wet Weight[1] (g/rep.)	220.0^a ± 16.1	206.7^a ± 13.3	266.7^a ± 29.6	250.0^a ± 25.2
SGR[1] (% /rep./day)	0.90^a ± 0.05	0.89^a ± 0.06	1.13^a ± 0.13	1.09^a ± 0.10
FCR[1]	1.01^a ± 0.08	1.07^a ± 0.07	0.85^a ± 0.10	0.90^a ± 0.08
Feed Fed (g/rep.)	220.0	220.0	220.0	220.0
Lettuce				
Biomass Gain[1] (g/rep.)		2639.4^k ± 28.9	2338.1^m ± 14.5	2159.0^n ± 9.8
Yield[1] (g plant^{-1})[1]		131.97^k ± 6.46	116.91^m ± 3.24	107.95^n ± 2.20
Yield[1] (kg m^{-2})[1]		5.05^k ± 0.25	4.47^m ± 0.12	4.13^n ± 0.08
Nutrients				
Phosphate[1] (mg L^{-1})	7.15^a ± 1.03	3.42^b ± 0.11	3.47^b ± 0.94	3.91^b ± 0.37
Nitrate[1] (mg L^{-1})	51.23^a ± 1.58	4.63^b ± 2.85	2.60^b ± 1.84	15.70^c ± 2.57
Phosphate (g/rep.) [y]	0.80	0.38	0.51	0.40
Nitrate (g/rep.) [y]	5.74	0.52	0.39	1.62
Phosphate removal (%) [y]		52.5	36.3	50.3
Nitrate removal (%) [y]		90.9	93.2	71.8

[1]Values are means ± S.E
k, m, n: values showing the same letter are not significantly different (P>0.05, n=60) (Anova)
a, b, c: values showing the same letter are not significantly different (P>0.05, n=3) (Mann-Whitney)
y: values are calculated from mean final nutrient concentration per unit volume of test system replicate
SGR: specific growth rate (% day^{-1}): [(ln final wt. – ln initial wt.)/(time (days))]x100
FCR: food conversion ratio: feed fed/(wet weight gain)

Aquaponics 經濟效益評估與市況調查

- 夏威夷州立大學針對群島上小規模養殖水耕農場進行經濟效益評估結果，30年之修正後內部回報率為8~13%。
- UVI針對不同規模農場進行經濟效益評估，比較6、12和24個UVI單位的農場規模，其投報率分別為11.1%、17.9%和21.7%。

Table 1 Summary of the Farms

	Farm A*	Farm B	Farm C
Location	Waianae, Oahu	Kunia, Oahu	Mililani, Oahu
Total raceway surface area (sq ft)	11,520	12,288	28,600
Total fish production capacity (fish tank volume combined) (gal)	15,000	6,000	75,000
Types of vegetables	Lettuce	Lettuce	Lettuce, Tomatoes, Cucumbers, Beets
Types of fish	Tilapia	Tilapia, Chinese Catfish	Tilapia, Chinese Catfish
* Farm A annual sales volumes are based on the expected production volume.			
Annual sales volume (vegetable, lbs)	183,209	62,400	66,221
Annual sales volume (fish, lbs)	1,252	0	15,643

Table 7 Operational Cost

	Lettuce		Fish		Total	
Labor	29,924	57%	1,918	14%	31,842	48%
Electricity	11,890	23%	3,242	24%	15,132	23%
Water	3,265	6%	890	6%	4,155	6%
Seed and seed bed	1,122	2%	-	0%	1,122	2%
Feed	-	0%	7,216	52%	7,216	11%
Chemicals	1,209	2%	-	0%	1,209	2%
Machinery and equipment fuel cost	3,122	6%	-	0%	3,122	5%
Land rental cost	1,874	4%	511	4%	2,385	4%
Total	52,406	100%	13,777	100%	66,183	100%

Table 10 Annual Production and Sales Income

	Lettuce		Tilapia	
Price	2.15	USD per lb	5.00	USD per lb
Annual production	35,820	lbs	4,200	lbs
Annual sales income	77,012	USD	21,000	USD

Figure 2 Net Income and Net Cash Flow

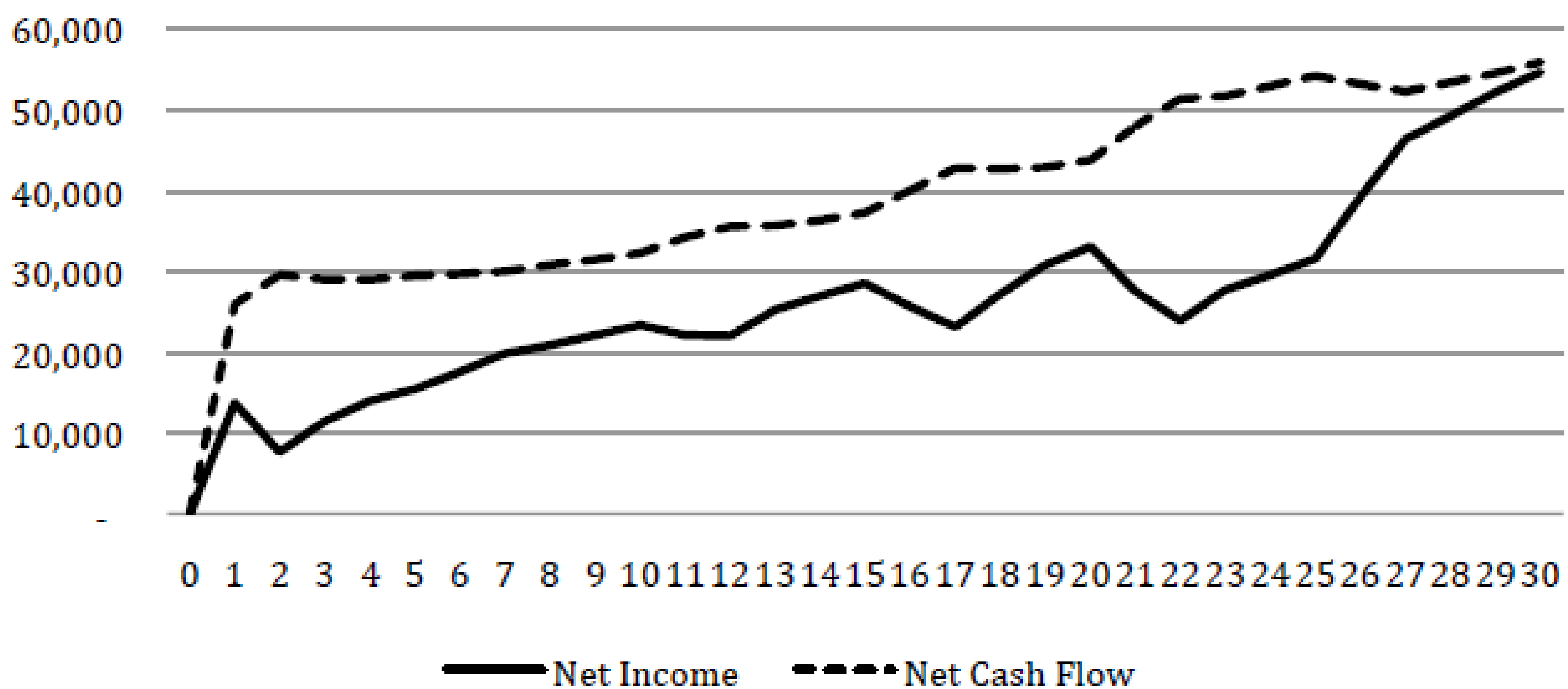


Figure 3 MIRR Sensitivity to Parameter Values

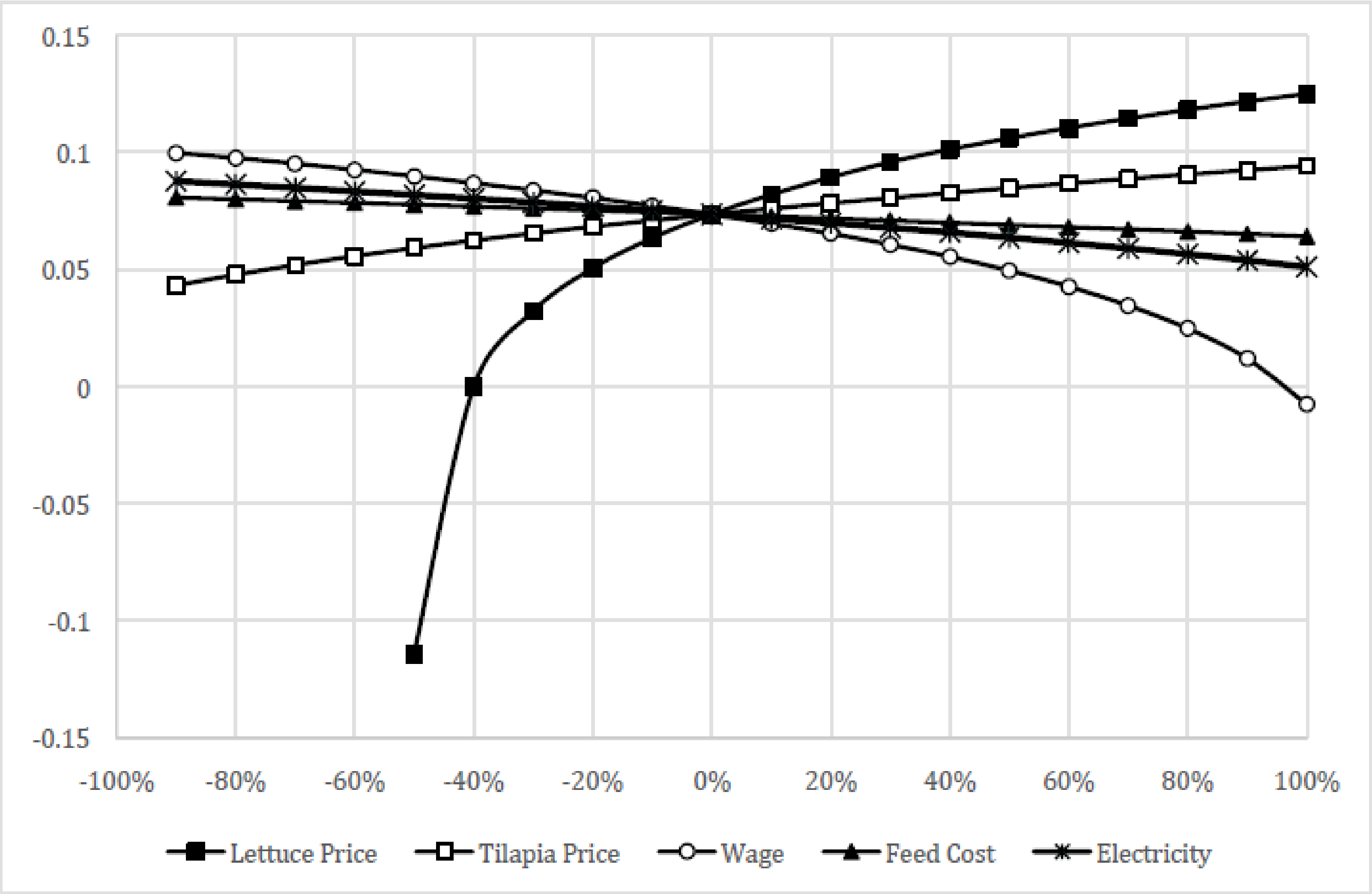


Table 7. Enterprise budgets for three model aquaponic farms with 6, 12 or 24 tilapia and lettuce production units, and necessary infrastructure to support fingerling production, lettuce seedling production, water storage, land costs and general overhead.

		Value or Cost per 6 units ($)	Value or Cost per 12 units ($)	Value or Cost per 24 units ($)
Revenue				
	Fish	102,334	204,668	409,336
	Lettuce	218,400	436,800	873,600
Total Revenue		320,734	641,468	1,282,936
Variable Cost				
	Fish	138,096	233,692	452,384
	Lettuce	118,321	209,143	418,286
Total VC		256,417	442,835	870,670
Income Above VC		64,317	198,633	412,267
Fixed Cost				
	Fish	11,380	22,760	45,520
	Lettuce	10,977	21,953	43,907
Total FC		22,357	44,714	89,427
Total VC and FC Costs		278,774	487,548	960,097
Net Returns		41,960	153,920	322,840
Other Costs		11,199	22,400	44,801
Total of All Costs		289,973	509,949	1,004,898
Returns to Risk		30,761	131,519	278,038

Farm size	6	12	24
NPV (20%)	$(127,655)	$(60,208)	$116,508
IRR	11.1%	17.9%	21.7%

美國約翰霍普金斯大學網路調查

- 2013年5~10月在257個問卷答覆者中，198(81%)來自美國，澳大利亞12個，加拿大10個，英國3個，菲律賓2個及其餘18個國家地區。
- 以小規模農場產地直銷、餐廳契作或農民市集銷售管道為主。
- 普遍生產作物以各類蘿勒(81%), 沙拉生菜(76%), 羅勒以外香草(73%), 番茄(68%), 結球萵苣(68%), 羽衣甘藍(56%), 葉用甜菜(55%), 小白菜(51%), 青椒(48%)及胡瓜(45%)。
- 平均魚類年產量為50~99磅，平均蔬菜產量為100~499磅，設施因經濟及生物環境考量以供蔬菜生產使用為主。
- 24%的問卷答覆者過去12個月沒有收穫漁獲，可能多為新加入者。在257個問卷答覆者中，95個只出售魚菜產品，69個只出售設備或技術諮詢，其餘93個兩種都出售。

Methods for hydroponic plant production.

Hydroponic method(s)	Percent of respondents (n = 186)[c]
Raft, media bed	26
Raft	14
Media bed	13
Raft, media bed, NFT[a]	10
Raft, media bed, NFT, vertical tower	9
Raft, media bed, vertical tower	8
Raft, NFT	3
Media bed, vertical tower	3
Vertical tower	3
Raft, media bed, NFT, vertical tower, wicking bed	2
Other combinations of methods[b]	10

[a] NFT = nutrient film technique; a fine mist of water is sprayed or dripped onto plant roots in a horizontal gutter or tray design. Similar to vertical towers except horizontal.

[b] Thirteen other combinations of plant production methods were each performed by two or fewer respondents.

[c] Data from respondents who sold aquaponically-raised plants or fish.

Weight of commercial fish and plant harvests in the previous 12 months.

Amount (kg) [a]	Percent of respondents[c]	
	Fish harvest (n = 185)	Plant harvest (n = 184)
0	24	2
0.45–22	19	14
23–45	12	15
46–226	15	21
227–453	14	16
453–2268	8	18
2269–4536	2	4
4537–22,679	5[b]	7
22,680–45,359	–	2
>45,360	–	2

[a] Originally in the survey categories were reported in units of pounds, and were later converted into kilograms.

[b] These fish harvests were reported in the survey as >4537 kg.

[c] Data from respondents who sold aquaponically-raised plants or fish.

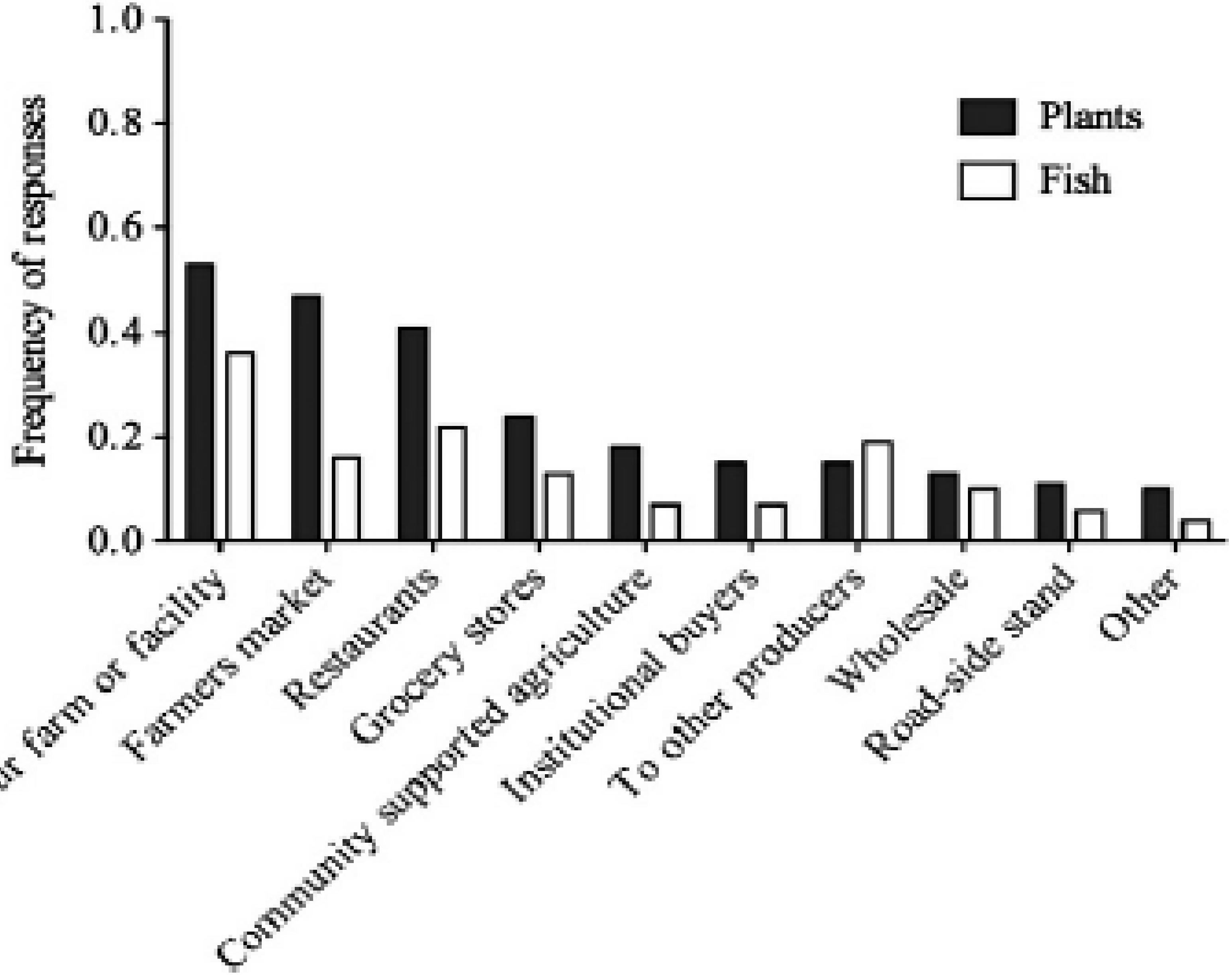


Fig. 1. Markets for plants and fish raised in commercial aquaponics systems used by respondents (n = 188).

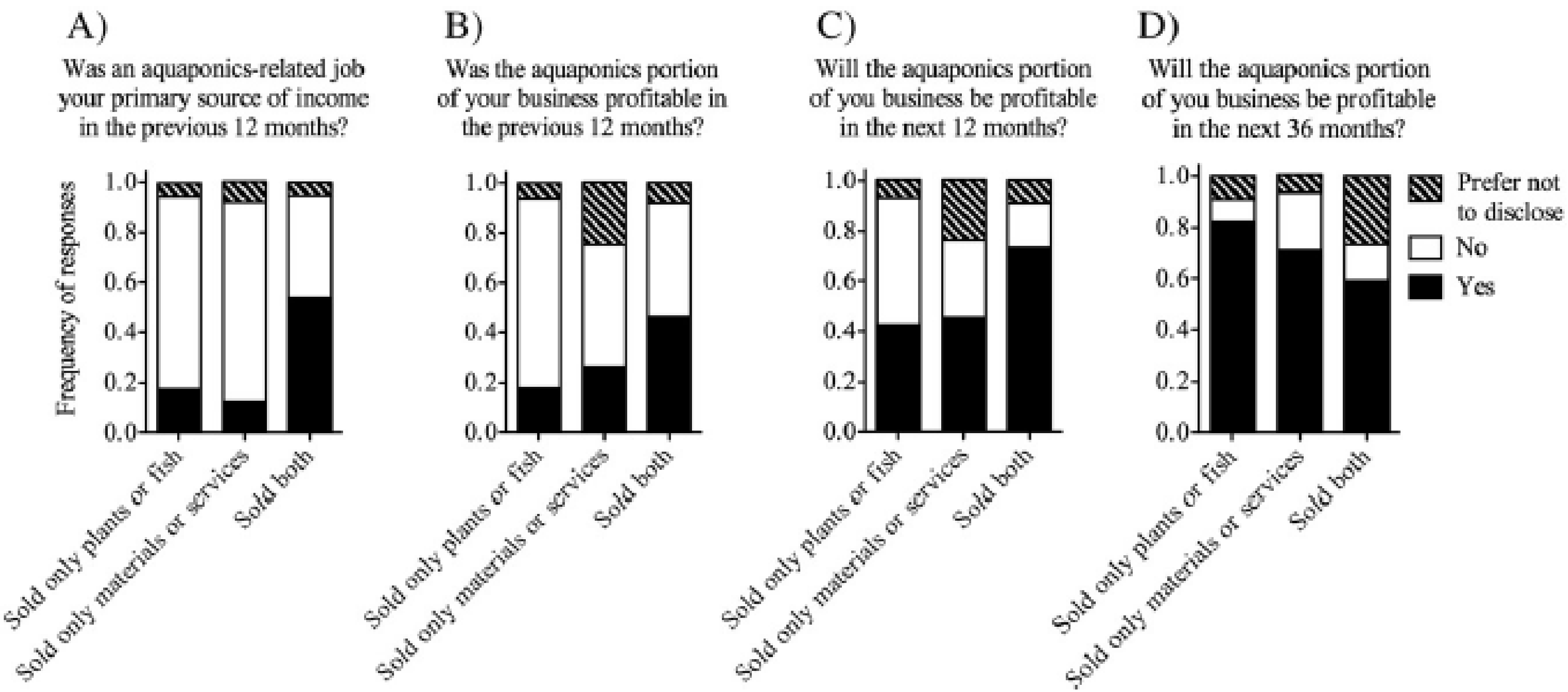


Fig. 2. Respondents views on A) aquaponics-related income, B) profit in the previous 12 months, and projections for C) profit the next 12 months and D) 36 months.

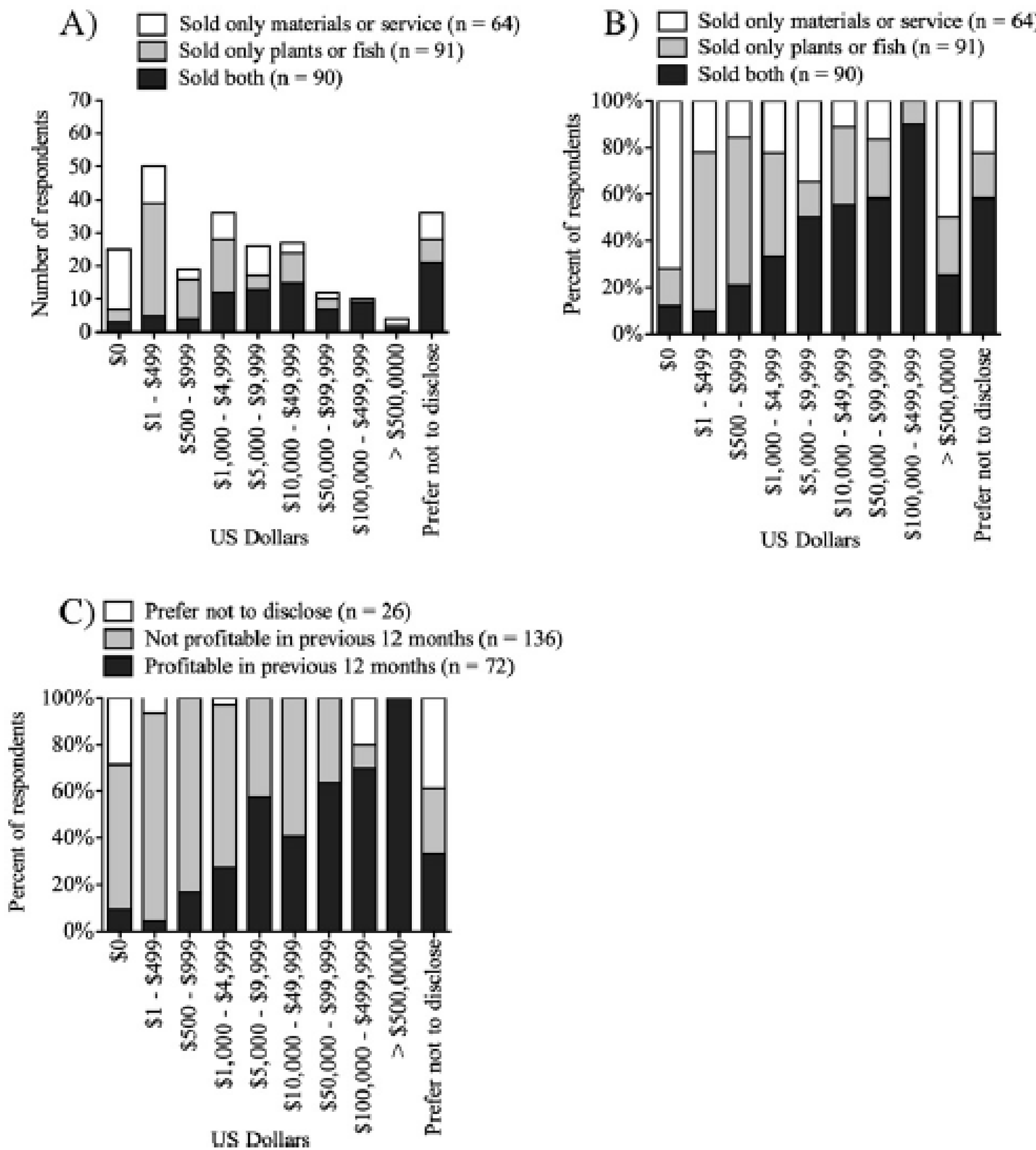


Fig. 3. Gross sales revenue in the previous 12 months by A) the number of respondents among three groups, and B) the relative response rates among three groups. Gross sales revenue was compared to C) respondent self-reported profitability in the previous 12 months.

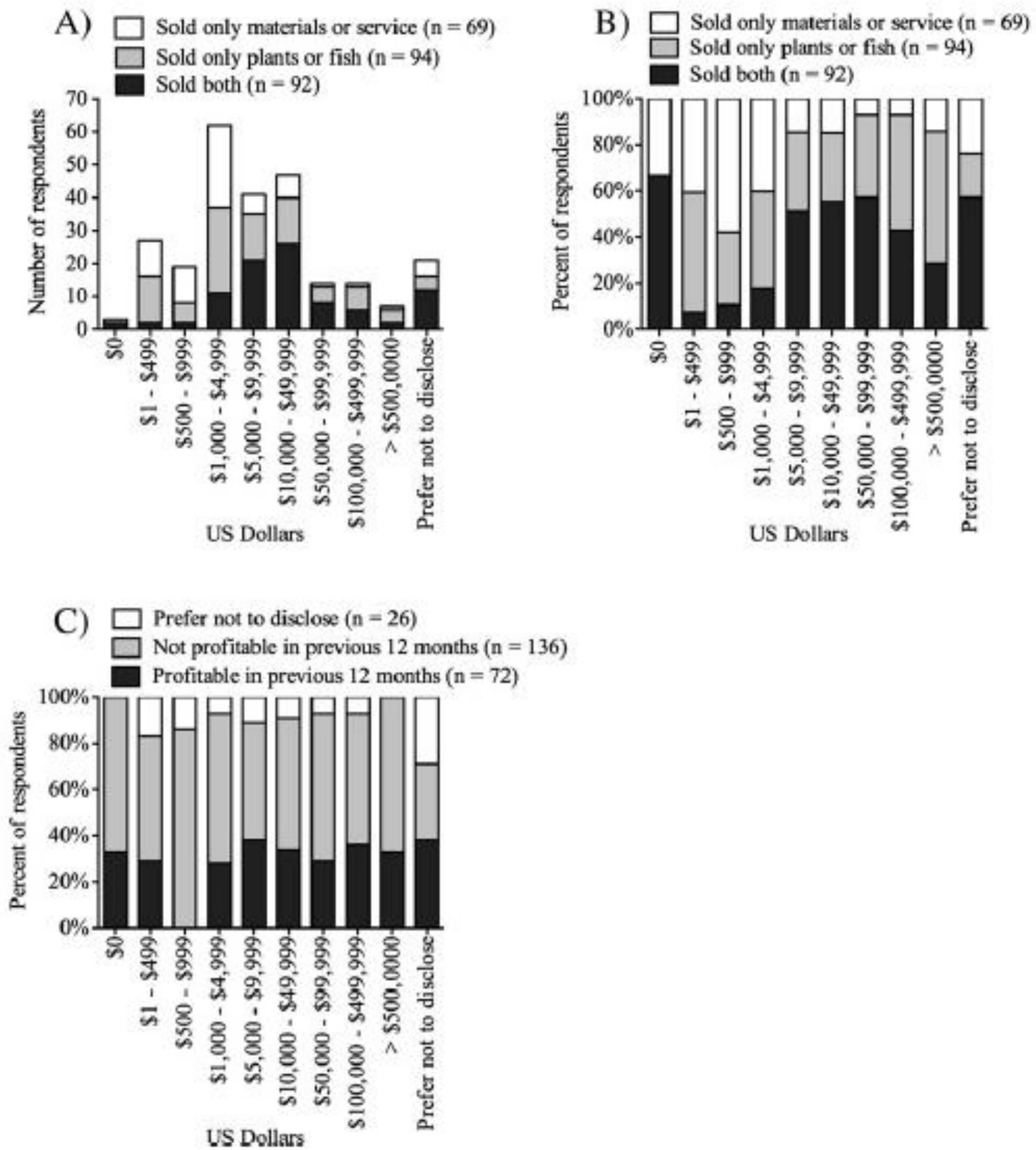


Fig. 4. Investments in the previous 12 months by A) the number of respondents among three groups, and B) the relative response rates among three groups. Investments were compared to C) respondent self-reported profitability in the previous 12 months.

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Aquaculture expert helps build one of the world's biggest fish farms in Middle East

NSW Country Hour By Laurissa Smith

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Posted 17 Mar 2015, 10:32am

There is sand as far as the eye can see and daily temperatures soar to about 50 degrees.

On the face of it, is is probably not the ideal spot to establish a fish and vegetable farm.

But this is the United Arab Emirates, a country where water is scare and so is locally grown food.

Some developers are trying to change that.

Over the years various companies have come up with ways to breed fish and use their waste water as fertiliser on vegetable crops.

In late 2013 aquaponics consultant Paul Van der Werf, from Queensland's Earthan Group, was invited to the UAE to build one of the world's biggest aquaponics systems.

The farm, now completed, consists of a 4,500 square metre shed which produces around 40 tonnes of tilapia.

The facility is also piloting a breeding program for juvenile barramundi.

PHOTO: Aquaponics consultant Paul Van der Werf in front of a poly greenhouse in the United Arab Emirates (Paul Van der Werf)

MAP: Griffith 2680

AUDIO: Paul Van der Werf speaks about a large-scale aquaponics farm in the United Arab Emirates (ABC Rural)

NSW Country Hour

- Policy issues on the table at farmers' conference
- Hesitation when it comes to applying for carbon farming funding
- Blizzard conditions continue across NSW, with snowfalls on farms and many roads closed
- Agribusiness victims seek justice eight years on from tax scheme collapse
- Coalition denies split over Shenhua approval

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建立養殖水培系統試驗計畫

- Top-down的科專計畫
- 在淡水繁養殖研究中心竹北試驗場方面，比較養殖水耕系統和循環水養殖系統的差異。
- 台南區農業改良場所進行庭院型養殖水培系統研究，在循環水槽中放養錦鯉與紅吳郭魚，搭配混合栽培蘿勒、西洋芹、青蔥、冰花、萵苣、茄子等多種植栽，結果生長狀態良好。
- 本場利用埤塘水灌溉復耕農田，及埤塘上架設浮筏栽培方式進行試驗，對水耕蔬菜而言，埤塘水中氮、鉀及鐵均偏低，須補充否則對蔬菜產量與品質影響甚鉅，且埤塘上架設浮筏式之栽培設備之防風設計




水試所養殖水耕福山萵苣植體分析結果與有機土耕對照表

編號	N(%)	P(%)	K(%)	Ca(%)	Mg(%)
吳郭魚	2.61	0.24	0.8	1.22	0.36
大口鱸	2.43	0.19	1.1	0.79	0.22
土耕對照1	4.96	0.24	7.9	1.26	0.47
土耕對照2	4.48	0.29	8.5	1.19	0.44

水試所養殖水培空心菜植體分析結果與有機土耕對照表

編號	N(%)	P(%)	K(%)	Ca(%)	Mg(%)
1.大口鱸	3.73	0.20	0.9	1.72	0.51
2.吳郭魚	3.98	0.26	2.0	1.88	0.54
有機栽培1	4.61	0.40	6.9	1.32	0.31
有機栽培2	5.13	0.38	7.23	1.07	0.35
有機栽培3	5.32	0.41	10.02	0.90	0.30
有機栽培4	4.96	0.37	7.22	1.05	0.34

台南場目前成果

- 作物蒸散及養殖槽蒸發平均每月耗水量約16%(每月平均補水量556 L)/(養殖槽水容積3500L)。
- 夏季高溫對蔬菜栽培影響甚鉅，經試驗南蔥在高溫的環境下生長遲滯，而蕹菜生長狀況良好約12-14 天即可採收。
- 試驗發現水耕栽培作物有微量元素缺乏的問題，其中芫荽缺磷導致植株生長不良。蕹菜容易發生缺鐵導致葉片黃化生長變緩，經添加EDTA-Fe後約2-3天可獲得改善。

休耕田以埤塘水灌溉下不同施肥量對蔬菜產量之影響

作物產量與施肥量	青梗白菜 kg/m²±SD	福山萵苣 kg/m²±SD	紅莧菜 kg/m²±SD	蕹菜 kg/m²±SD	莧菜 kg/m²±SD
100%	2.8±0.8	3.2±0.4	1.3±0.2	1.8±0.02	3.2±0.62
75%	3.0±0.7	3.1±0.5	1.1±0.23	1.6±0.44	2.8±0.06
50%	2.4±1.2	2.8±0.7	0.5±0.16	1.1±0.03	1.2±0.13
25%	2.4±1.1	2.2±0.7	0.4±0.07	1.0±0.23	0.9±0.26

本場於埤塘試驗增設防鳥網情形，作物為福山萵苣與芫荽。

Table 3. Comparison of pH and nutrient concentrations in hydroponic and aquaponic solution for different plant species, all nutrients reported in mg L^{-1}.

Plant Species	System	pH	Ca	Mg	Na	K	TAN	NO_3-N	PO_4-P	SO_4-S	Cl	Fe	Mn	Cu	Zn	B	Mo	Source
Lettuce (*Lactuca sativa*)	Hydroponic	5–6.2	180	24		430	18	266	62	36		2.2	0.3	0.05	0.3	0.3	0.05	Sonneveld and Voogt, 2009 [69]
Lettuce (*Lactuca sativa*)	Hydroponic		200	50	50–90	210		190	50	66	65–253	5	0.5	0.15	0.15	0.3	0.05	Resh, 2012 [23]
Lettuce (*Lactuca sativa*)	Aquaponic	8				48		20	10									Al-Hafedh *et al.*, 2008 [70]
Lettuce (*Lactuca sativa*)	Aquaponic		180	44	17	106		137	9									Pantanella *et al.*, 2012 [71]
Basil (*Ocimum basilicum* 'Genovese')	Aquaponic	7.4	12	7		45	2.20	42	8			2.5	0.8	0.05	0.44	0.19	0.01	Rakocy *et al.*, 2004 [24]
Water spinach (*Ipomoea aquatica*)	Aquaponic	5.6–7.3						20	17									Endut *et al.*. 2010 [31]
Tomato (S																		Sonneveld and Voogt, 2009 [69]
Tomato (S																		Roosta and Hamidpour, 2011 [37]
Okra (*Abelmoschus esculentus*)	Aquaponic	7.1	24	6	14	64	1.58	26	15	6	12	1.3	0.06	0.03	0.34	0.09	0.01	Rakocy *et al.*, 2004 [38]

日期	Ca(mg/l)	Mg(mg/l)	K(mg/l)	NH_4^+-N (mg/l)	NO_3^-N (mg/l)	P(mg/l)	NO_2^-N (mg/l)	Fe(mg/l)
1/8	38.00	15.4	12.5	0.2	1.9	40	0.154	0.14
2/16	16.38	7.00	37.50	0.6	2.1	12.50	0.23	0.09
3/16	12.6	21.2	22.5	0	1.2	18.3	0.09	0.05

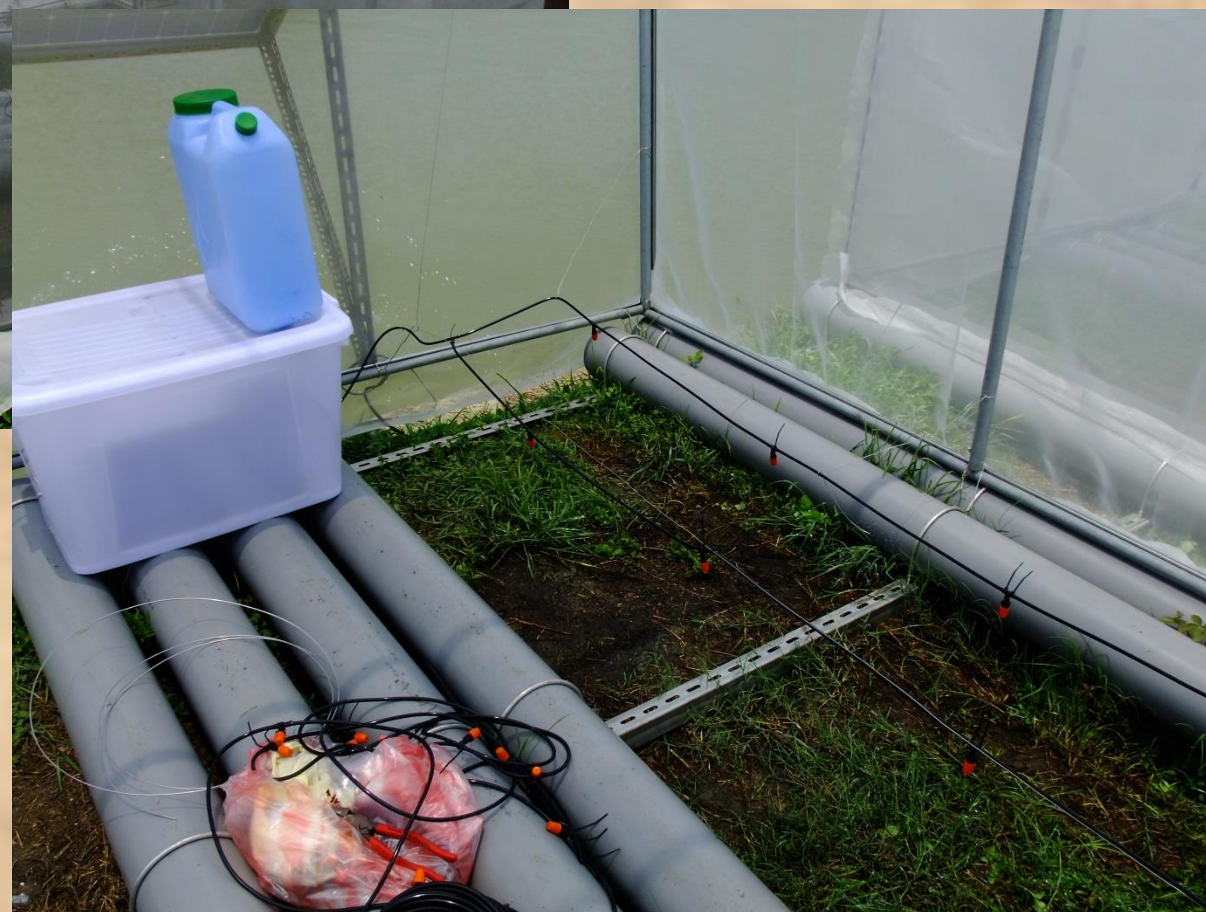
福山萵苣產量結果

處理	平均(最大)單株產量(g)	單位面積產量(kg/m^2)	乾物量(%)
蛭石	42(49)	1.0	6.7
發泡煉石	38(51)	1.0	6.1
混合介質	65(86)	1.6	5.8
保麗龍板	65(133)	1.6	5.0
土耕	120~150	3~4	4.5

福山萵苣植體分析結果

編號	N(%)	P(%)	K(%)	Ca(%)	Mg(%)
蛭石	3.46	0.16	6.1	0.87	0.22
發泡煉石	3.25	0.18	5.8	1.05	0.24
混和介質	3.18	0.16	5.9	0.94	0.22
保利龍板	4.24	0.21	8.3	1.10	0.23
土耕對照1	4.96	0.24	7.9	1.26	0.47
土耕對照2	4.48	0.29	8.5	1.19	0.44



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